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LEARNING THROUGH EXPERIENCE: GROUP DESIGN PROJECTS ON THE MASTERS COURSE IN AIRCRAFT ENGINEERING

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1. ABSTRACT

The successful completion of aerospace projects usually involves the bringing together of many different specialist skills. The need for aerospace engineers to be conversant with many disciplines and aware of the many facets of a project is today's reality. However, in today's working environment it is becoming increasingly difficult for individuals to achieve the necessary experience, with the timescales for major aerospace projects getting ever longer and their number decreasing.

The Group Design Projects within the Aircraft Engineering course have the specific purpose of addressing this issue. They provide the opportunity for aerospace engineers from a range of disciplines to be involved in a real project, with many of the difficulties and constraints of those they will meet in their working lives. These projects progress through the full design process and provide this experience within a limited time period and, relatively, limited risk environment.

In addition to meeting their basic objective, Group Design Projects commenced to-date have proved very demanding but provided further benefits to all concerned.

2. ABBREVIATIONS

ACSL	Advanced Continuous Simulation language
AE	Aircraft Engineering (course)
AVD	Aerospace Vehicle Design (course)
BAe	British Aerospace
BWB	Blended Wing/Body
CAA	Civil Aviation Authority
CAD	Computer Aided Design
CoA	College of Aeronautics
DERA	Defence Evaluation Research Agency
GDP	Group Design Project
GFRP	Glass Fibre Reinforced Plastic
LSWT	Low Speed Wind Tunnel
MA&A	Military Aircraft & Aerostructures
UAV	Unmanned Air Vehicle

3. INTRODUCTION

The Aircraft Engineering course is a three year part-time MSc course which comprises the same major elements as the very successful full-time MSc course in Aerospace Vehicle Design. That course has been running and attracting students from all over the world, with the same basic philosophy, since the College of Aeronautics(CoA) was founded in 1946.

The students on the Aircraft Engineering (AE) course attend lecture modules, perform a piece of individual research and work on a Group Design Project (GDP). It was this last element that particularly attracted the launch and predominant customer for the course, the then Military Aircraft Division of British Aerospace (BAe), with its basic philosophy of teaching the design process by placing someone in a project group with an individual responsibility but having to cater for the needs of the group as a whole. The basic objective of this is to provide a 'virtual industry environment' so as to better equip the students for the real situations in which they are likely to have to apply their aerospace engineering and science knowledge.

In this paper the basic organisation of the GDPs on the AE course is described, followed by details of all five GDPs commenced to-date. Due to both authors' direct involvement in the first GDP and one author's involvement in the third, these two will be described in rather more detail than the other three. Some general considerations, difficulties, plans for the future etc. are then discussed and finally some conclusions drawn.

4. GENERAL ORGANISATION OF GDPs

The GDP on the full-time course in Aerospace Vehicle Design concentrates on the initial design of parts of an aircraft, which has been previously defined in terms of basic geometry, mass, performance characteristics etc. by staff. However, BAe wished to address a greater extent of the design process in the AE MSc, with progression all the way from conceptual design, through preliminary and detailed design to manufacture, clearance and flight. In this way the students would, in the space of three years, be given first-hand experience of a much wider extent of an aerospace project than could ever be the case whilst working on major aircraft projects in a present military airframe manufacturer.

The detailed organisation of the GDPs on the AE course has varied slightly from one project to the next and in the sections covering each of the projects to-date these differences will be explained. However, there are some aspects which remain the same.

At present, there is no formal mechanism for choosing the subject of GDPs. It is hoped that this may change in the future but certainly there are a number of characteristics which are required for a subject to be suitable. To meet the basic objectives of the GDP, the subject must be such that it covers a wide extent of the whole design process from concept to flight and it is possible to do this within the constraints of a three year time frame, the effort available from the student group (with a little external assistance) and a restricted budget for the project. In addition, the subject should involve real clearance and safety issues (to concentrate the minds of all those working on the project) and should capture the interest of the students.

Paper presented at the RTO AVT Symposium on "Aerodynamic Design and Optimisation of Flight Vehicles in a Concurrent Multi-Disciplinary Environment", held in Ottawa, Canada, 18-21 October 1999, and published in RTO MP-35.

The projects commence soon after the beginning of each student intake's course and are formally progressed through GDP meetings held at regular intervals during the following three years. There is usually a meeting during each of the three lecture modules held at the CoA for that intake of students each year. In addition, there are usually two or three meetings in between these modules. These are usually rotate around the sites where the students are located and can give an opportunity to see and, in some case, make a tour around the sites, for the benefit of those who may not have visited them before.

The GDP meetings are jointly chaired by one member of staff from CoA and one senior engineer from BAe. The chairmen are directly involved in ensuring the overall progression of the project. However, they also act as a source of information and contacts, at BAe and CoA, useful to assist in the project.

In addition to the formal GDP meetings, the students are likely to hold further meetings, of the whole or part of the group, to address particular aspects. It has also been the case that the system of formal Design Reviews, used by BAe on there own projects, has been applied to the GDPs, though in a reduced fashion appropriate to the scale of these projects. This has both exposed the students to necessary preparation for such formal Reviews and performed the real function of subjecting the GDP work to the scrutiny of experienced engineers, independent of the project, to support the case for clearance to fly the results of the project.

As the GDP forms part, in fact the largest single part, of the assessment on the AE course, there is individual output required from each student on their personal contribution to the GDP. This takes the form of interim reports/presentations at around one and two years into each GDP that count towards a small part of the GDP assessment. The major part of the GDP assessment is through submission of a GDP final report or 'thesis'. This is submitted 3 months prior to the end of the student's three year course. Ideally, this would be following conclusion of the real work on the project. However, in practice, for the student intakes that have completed the course to-date, the GDP has not been completed at the point of submission of their GDP thesis. This is not a problem in terms of academic assessment of the work and, due to BAe's commitment to the GDPs, has not proved to be a problem in the students working on the GDP to see it to a real conclusion.

The tasks to be performed within the project, their size and whether they exist for the full length of the project obviously depend on the subject of the GDP. However, as a general principle, students are encouraged to have at least some say in selecting which tasks and responsibilities they will take on. This allows a student to either stay in an area with which they are familiar or broaden their own personal experience whilst possibly providing guidance to other students in there normal sphere. There is, of course, a need to cover all the necessary tasks and responsibilities for the project. Therefore, there sometimes needs to be an element of gently persuasion to ensure this is the case.

5. GDP FOR THE 1995 INTAKE

The Aircraft Engineering course was launched in February 1995 with 15 students, all from BAe Military Aircraft. The GDP that they were presented with was to work on modifications to Cranfield's own single seat A1 aerobatic aircraft, which had resulted from previous MSc student work, to provide a two seat aerobatic trainer. This provided the realistic possibility for a project to progress through to manufacture and flight. However, it should be noted that at the outset there was no guarantee that it would do so.

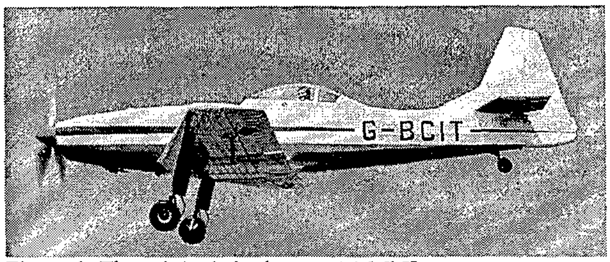

Figure 1 The original single-seat A1 MkII.

5.1 Initial Conceptual Phase

The students had been set an exacting specification for the two seat aircraft, with performance equal to or better than that of the existing single seat version, the A1 MkII, Fig. 1. This was an intentionally difficult requirement for an aircraft to be produced by modification , in order to get the students to consider some fairly radical modifications or even starting again with a blank sheet of paper.

	Existing A1 MkII	Two-Seat A1
Max. level Speed	76.1 ms^{-1}	80 ms^{-1}
Climb Rate	13.5 ms^{-1}	12.5 ms^{-1}
G limits	+7/-5	+6/-3
Roll Rate	150 deg/sec	150 deg/sec
Range	238 km	800 km
Stall Speed	25 ms^{-1}	25 ms^{-1}

Table 1 Comparison of the specification requirements set for the two-seat A1 with that of the existing A1 MkII.

During the initial phase, the students worked in three competitive groups, initially designated the Red, Blue and Green teams, to consider and present approaches to meet the specification. However, the students had soon renamed these the 'Well Red', 'Blue Sky Project' and 'Cranfield Aerobatic Project' teams.

Following consideration of a number of options by each team, they presented their chosen approach to the 'customer' consisting of senior staff of BAe and CoA. Not surprisingly, it was clear from the options presented, that the initial specification could only be met by major modifications to the existing airframe of the A1 and/or re-engining with a more powerful unit. Therefore, the 'customer' chose to specify a list of what became known as 'affordable' modifications to be progressed through the remainder of the project.

5.2 Definition of Individual Responsibilities

The affordable modifications were defined to provide the aircraft with a basic two seat capability and increased range with an attempt to approach the other specification requirements without the need to resort to replacement of major airframe elements or the engine. These modifications were split into the following task areas, each the responsibility of a student:

- Canopy
- Trailing Edge Flaps
- Fuel System Extension

Front Cockpit Seat, Controls and Instruments
Electrical System Extension

In addition, to these, however, some more radical changes were also to be progressed by other students. These would allow the possibility of meeting, or more closely approaching, the full list of requirements. These 'major' modifications, as they were termed, were as follows:

Composite Wing Design
Semi-Monocoque Metal Fuselage Design
Composite Fuselage Design 1
Composite Fuselage Design 2

The distinction between the two composite fuselage designs was to be that one would be suitable for one-off production, and thus treat production costs as paramount, whilst the other would treat the minimisation of mass as most important, and thus may only be suitable for series production.

As well as specific changes to the aircraft, a number of generic tasks, to be covered what ever changes were adopted, were also identified as necessary and defined as a responsibility of a student. These were:

Performance Evaluation
Wind Tunnel Testing
Mass & C.G. Control and Stability & Control Issues
Load and Fatigue Analysis
Structural Dynamics and Aeroelasticity
Flight Test, Instrumentation, and Certification

The student given the responsibility of Performance and Evaluation was also given that to design modified wing/fuselage fairings and wheel spats, which had been identified as a possible means of reducing drag. Whilst all the students needed to consider aerodynamic aspects, as they impacted on there particular area of responsibility, it was in these generic tasks that aerodynamics was particularly addressed.

5.3 Modification Design Phase

From the point that the students individual responsibilities were defined, they worked on as a single group, holding regular project review meetings. Professor Denis Howe had initially taken on the role as CoA GDP chairman and, due to his invaluable experience of the A1, was heavily involved in the project through-out. However, in February 1996 Robert Jones took on the role as CoA GDP chairman, joining Roy Scott, who was acting in this capacity for BAe.

Each of the students produced a statement of work for their responsibility area. These were then considered together to define the necessary timescales, due to dependency on outputs from other students.

Twelve months into the project a major Design Review meeting was held at Cranfield. At this the students presented their work to that date and plans for the remainder of the project to senior staff of BAe and CoA, again acting as the 'customer'. As a result of this, the commitment of both BAe and CoA to carry the project through to manufacture and flight was confirmed. Shortly after this, one of the students left BAe and his responsibilities for the cockpit controls etc. were redistributed amongst the other students.

Over the following few months facilities for manufacturing the necessary components within BAe and, where necessary, externally were investigated. Initial costs for manufacture, bought out items and installation on the aircraft were gathered with one of the students taking on the role of co-ordination of these production related activities.

By approximately 18 months into the project it was clear that the students' other work commitments was slowing progress on the designs for affordable modifications to the extent that manufacture and installation could not be achieved within the timescale of the course. Therefore, BAe, took an important step in agreeing to students working on the affordable modifications taking part in an intensive two week placement at CoA to progress the designs with the advantage of co-location with the aircraft and the existing A1 drawings and information. In addition to the students who had responsibility for the affordable modifications, the other students and some senior engineering personnel from BAe joined the placement to assist in the design work for at least part of the two weeks. At this stage it was also decided that, due to the urgent need to progress the affordable modifications, teams for each modification would be formed with the student whose responsibility it initially had been acting as task leader. This required that work on the major modifications had to be suspended. Although it was the originally intention that the students working on the major modifications would return to these tasks once the affordable modification designs were completed, in practice little time remained to do this at the end of the project.

It was at this time that a second student, with the responsibility of the canopy design, left BAe. Thus, a further redistribution of responsibilities was necessary. One of the students, who had originally had one of the major modifications as his responsibility, took on this task.

The decision by BAe to allow the two week placement and the significant cost involved in the loss of students from their other commitments for that period was very important. During this period the state of the design for all the modifications was significantly advanced, providing an impetus without which the project would have been very difficult to complete.

5.4 Progression to Manufacture

Once drawings produced by the students were completed, these were checked, along with stressing calculations etc., by a further nominated student at each BAe site before despatch to Cranfield. The CoA retains full Design Authority on the A1, so whilst the drawings had been produced and checked within BAe and were usually issued back to BAe for manufacture, they were also checked by the Aircraft Design Group within Cranfield Aerospace Ltd. In particular, Chief Stressman Phill Stocking took on the responsibility of checking and issuing on behalf of the CoA.

The CoA had held discussions with the Civil Aviation Authority (CAA) at an early stage to inform them of intentions with regard to the modifications and discuss necessary procedures for certification in this case. The original A1 design had been performed to the British Civil Airworthiness Requirements, Section K. However, these have now been superseded by the Joint Aviation Requirements, Part 23. Thus, it was necessary to determine which areas should remain covered by the original requirements and which needed to satisfy the newer ones. The CAA were kept informed of progress and consulted on issues, as necessary, through out the project.

The majority of manufacture of items was performed by BAe at its Brough and Warton sites and for this purpose drawings and orders were issued to BAe for these. Therefore, BAe became a supplier to the CoA and, to satisfy the CoA's quality procedures, the CoA's Quality Co-ordinator and Chief Aircraft Inspector had to visit the BAe sites to assure himself that they were a fit supplier!

The CoA purchased all bought out items and, if necessary, issued these on to BAe for inclusion in the component assemblies to be supplied back to the CoA. At an early stage it was realised that there were a number of differences in methods and procedures between BAe and CoA. However, as the process of issuing drawings for manufacture commenced, other differences emerged and solutions to these were discussed and agreed, with up-dating of drawings etc. as necessary.

In order to progress the final stages of the design and address manufacturing issues as they arose, the full GDP review meetings, attended by all students, were supplemented by weekly progress meetings using teleconferencing between task leaders on the major modifications and others, as necessary.

5.5 Installation and Assembly of the A1-200

By the end of 1997 the initial components produced by BAe began to arrive at Cranfield for installation on the aircraft. In the meantime the aircraft had been substantially dis-assembled and stripped of its fabric covering . Necessary maintenance work on the airframe and in particular its undercarriage was performed. In addition, some preparatory work for modifications to the aircraft being worked on by the second (1996) intake on the Aircraft Engineering course was also performed.

Installation of the modification components on to the aircraft began with the items placed within the fuselage, prior to its re-fabricing. These included the control extensions, seat and instruments for the forward cockpit, the battery tray and mounting for a new GPS navigation/radio unit in the rear cockpit. The fuselage was then re-covered and painted, along with the wing, in a colour scheme to match the CoA's other aircraft. Next the canopy, which had been trial installed prior to re-covering, to ensure the new latching and hinging interface details were correct, was fitted.

5.6 Wind Tunnel Testing

Whilst manufacture of the canopy was progressing, one of the students, responsible for wind tunnel, testing was investigating the aerodynamic effects of it. The 1/7 scale wind tunnel model of the A1, produced during the original design work on the aircraft, was taken to BAe Warton and after some restoration work was used in the 4.0 m Low Speed Wind Tunnel (LSWT) facility there to investigate the effect of external modifications. The changes investigated included those from the addition of the trailing edge flaps but the canopy changes represented a major part of the tests carried out, Fig. 2.

The wind tunnel model had two new canopy shapes added to it for these tests, one representing a canopy composed of three single curvature shapes and a second modelling the canopy shape actually produced. Both these new canopy shapes were produced directly from Computer Aided Design (CAD) models using stereo-lithography techniques. The tests performed showed that canopy of the actual shape used had insignificant effect on the drag and acceptably small effect on stability derivatives.

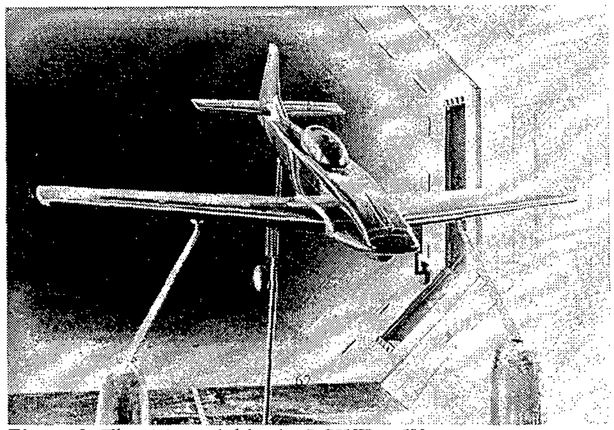

Figure 2 The A1 model in the LSWT at Warton

Whilst these wind tunnel tests did not identify any real problems for the two seat aircraft. They did provide a useful lesson in the measures necessary during the collaboration between organisations. The 4 m tunnel at Warton has a substantially automated system for recording measurements and converting them directly into the various non-dimensional derivatives. Initially, their appeared to be a significant alteration in the value of some of the lateral derivatives. However, it was then realised that the difference was almost a factor of two and the reason was the definition of non-dimensional derivatives produced by the Warton analysis system did not match with the standard notation used to define the same derivatives for the original two seat A1. This provided a useful reminder that even things which are expected to be and apparently are the same in different organisations may not be and should always be checked.

5.7 Predictions for the A1-200

It is worth noting at this stage that the other students with generic responsibilities showed through their work that structural dynamic problems would not result from the modifications (in particular the flaps), centre of gravity travel would remain basically within the limits of the A1 MkII and basic empty mass of the A1-200 would be just under 100 kg greater than the A1 MkII. The final generic task student, working on performance evaluation, predicted that whilst the A1-200 should meet or exceed the requirements set in the specification for range and roll rate and almost achieve those for maximum level and stall speed, it would fail to achieve the climb rate by a substantial margin, at only 10.6 ms^{-1}. However, without a substantial reduction in airframe mass and/or drag or a more powerful engine, it was accepted that this requirement could not be met.

5.8 Conclusion of the A1-200 Project

Following re-assembled in its two-seat configuration, the aircraft was readied for its official Roll-Out at Graduation Day on 12 July 1998. On that day all 13 of the students, who completed the course, graduated with a Masters in Aircraft Engineering. This must be judged a considerable achievement on their part. Whilst playing their part in the GDP work on the A1, they had attended and been assessed in lecture modules, performed research work on an individual topic, produced theses on there individual research and GDP responsibilities as well as holding down a full-time job at BAe and meeting their family commitments.

Following the roll-out the aircraft underwent further preparation and ground test prior to first flight. The official first flight took place on 30 September 1998, when the CoA's own Chief Test Pilot, Roger Bailey, provided a limited display of the aircraft in front of an audience of invited guests from industry and the media, following naming of the aircraft the Cranfield A1-200 'Eagle' by Dr Kenny-Wallace, Vice Chancellor of the BAe Virtual University, Fig. 3.

Figure 3 First demonstration flight of the A1-200 Eagle.

A great deal of documentation was created during the course of this project including meeting minutes, formal drawing, stressing calculations, orders etc. Much of this has now become part of the formal records of the A1 and is unpublished. However, for further detail on the project as a whole and the individual tasks performed by the students reference can be made to their GDP thesis (Refs. 1-13) which are lodged in the Cranfield University Library.

6. GDP FOR THE 1996 INTAKE

Ever since the A1 aerobatic aircraft first flew in 1976 there have been attempts to improve its capabilities and flying qualities. In particular, the following year the aircraft had a more powerful engine fitted than the original unit and a larger rudder. Even so, there are still aspects of the aircraft's handling qualities which could be further improved upon. One particular aspect is that the aircraft's flick roll capabilities leave something to be desired.

It has been generally accepted that the major factors affecting the A1's flick roll capabilities were a rudder effectiveness, which was too small in comparison to the aircraft's directional stability, and development of wing stall close to the root in the initial stages of the manoeuvre. Various measures had been introduced and attempted to address these problems including:

- Increase in rudder horn size
- Reduced size dorsal fin
- Removal of dorsal (subsequently replaced due to tendency to rudder overbalance)
- Addition of undercarriage leg fairings
- Measures to clean up flow over lower rudder

The problem with the lower rudder was the 'step' between the relatively wide fuselage and narrow fin was causing separation and thus loss of rudder effectiveness.

In 1989 a dedicated series of flight tests on the aircraft, using triangular stall breaker-strips on the wing leading edges at approximately mid-span of the ailerons and vortex generators on the rear fuselage in front of the lower rudder, provided a significant improvement in the aircraft's flick roll characteristics. The breaker strips were found to produce some problems at high incidence and during spin recovery but the tests had proved the possibilities of improving flick roll performance. Therefore, the students on the 1996 intake of the AE course were set the task of improving the A1's lateral stability and control characteristics, in the knowledge that the aircraft that they would modify should, by then, be a two seat aerobatic trainer.

The GDP chairmen for the project were initially defined as Steve Jones from BAe Salmesbury and Steve Molnar from the CoA. However, Phill Stocking took over the role for the CoA when Steve Molnar left to return to BAe Airbus after approximately 12 months of this GDP.

Unlike the 1995 intake GDP, the 12 students who began the course were allocated individual responsibilities on the project from the beginning. These were initially as follows:

- Aerodynamic and CFD Analysis
- Novel Concepts
- Fin Design
- Structural Test
- Flight Controls
- Rudder Design
- Tailplane and Elevator
- Manufacture
- Fuselage Investigation
- Fatigue and Fracture
- Performance and Stability
- Project Management and Flight Test

However, during the first year of the course four students withdrew and a significant reallocation of tasks became necessary.

As might be expected, the modifications to the aircraft concentrated on methods of improving the flow over the lower section of the rudder but other methods of improvement were also considered. A lack of torsional stiffness of the rear fuselage was considered to be possibly adding to the loss of rudder effectiveness and thus one student investigated methods of increasing the stiffness of the tubular steel structure in this area. Another student considered novel methods of reducing the aircraft's lateral stability by addition of a 'canard fin' either above or below the forward fuselage or increase of size of the undercarriage leg fairings. Whilst none of these possibilities was in fact carried through to be embodied as actual modifications on the aircraft, they did form a useful part of the survey of possible approaches.

In practice, the major modification selected for progression to manufacture was the design of an increased thickness rudder and matching fin removing the step at the end of the rear fuselage. This required modifications to the control circuits for rudder and elevator in the rear fuselage area, of the dorsal fin and fin to tailplane fairings.

Fortunately, the modifications to the control circuits had been defined when the fuselage fabric was removed during the work prior to the installation of the modifications for the A1-200 and, therefore, could be achieved with little disruption. Some of the preparation for other changes, for what was termed the A1-400, were also made at this stage.

Whilst there was no specific requirement to do so, considerations of weight linked to the experience it would provide led to the choice of composites for the new fin and rudder to be manufactured for the A1-400. However, in considering the likely cost of production of two fins and

rudders, one for flight and one for structural test, it was found sensible to consider production of these items outside BAe. Following survey of and discussion with a number of potential manufacturers, Slingsby Aviation Ltd were chosen to manufacture the composite components incorporating metal hinges and brackets etc. produced within BAe.

The type of structure chosen uses substantially monolithic Glass Fibre Reinforced Plastic (GFRP) spar and rib construction with GFRP skins, Fig 4. This structure is being produced by manual wet lay-up of cloth laminates, with inclusion of metallic, foam and wood components as necessary, using minimum tooling.

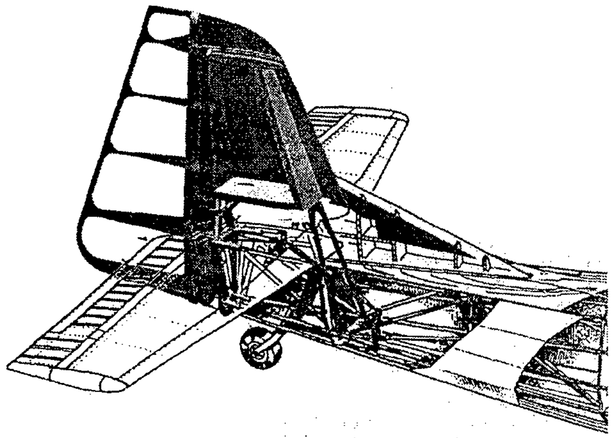

Figure 4 CAD representations of the GFRP fin and rudder for the A1-400.

The process of production of drawings and calculations by students followed by approval and issue by Cranfield Aerospace, as for the A1-200 modifications, was again followed in this case.

At the time of writing, seven of the eight students, who remained on the course at the end of the three years, successfully graduated in June 1999. The eighth student has been granted an extension to perform work towards his individual thesis. However, the GDP is not in practice complete. An order has now been placed with Slingsby Aviation for the two fin/rudder sets, with delivery to Cranfield planned for October 1999. One set will then be statically tested, prior to fitting of the second set to the aircraft for flight. It is possible that a first flight of the A1-400 may occur during 1999 but this is likely to be dependant on the weather.

Further detail on the A1-400 GDP and the student's individual work can again be found in the GDP thesis that they have produced (Refs 14-20).

7. GDP FOR THE 1997 INTAKE

Whilst the GDP subjects for the 1995 and 1996 intakes picked-up on Cranfield's unique position as a University having its own aircraft and holding design authority and approvals to modify it, the subject chosen for the 1997 picked-up on another unique area of the CoA's experience.

The CoA has for many years worked for and along with the UK Defence Evaluation and Research Agency (DERA) on development of all the aspects surrounding small Unmanned Air Vehicles (UAVs) particularly for surveillance purposes, Ref 21. For the 1997 intake GDP it was decided to utilise this experience to assist in the production of a UAV, to be designed from scratch, which would provide a tool for the investigation of the characteristics and suitability of various flight control laws and strategies when applied to unconventional aircraft configurations. This also recognised a rapidly growing general interest in the use of UAVs for various roles.

7.1 Specification

The initial specification for the UAV provided to the group of 16 students who started the course was, intentionally, rather vague but contained the following key design drivers:
1) The aircraft should be powered by jet propulsion with the capability of operation for around 15 minutes.
2) It should be able to take-off from its own landing gear, which should either be initially retractable or with the intention to retract it at a later stage, and approach speed should be limited to around 40 kt.
3) It should be capable of operating within the confines of a suitable airfield without the need for bank angles in excess of 45 degrees.
4) Adequate safety provision, in the event of a failure, should be provided to minimise the risk to third parties or property.
5) The vehicle span should be less than 2.5 m and its mass low enough to allow two people to safely lift it.
6) The vehicle should be of novel configuration to investigation of the characteristics of such a configuration, preferably with a construction which would allow alterations to the configuration without major alterations to the central core systems/engine element of the vehicle.

To minimise the work, and risk, involved in development of all the electronics and associated sensors and systems necessary to fly and control the UAV, permission was sought from and granted by DERA to use the electronics package developed by CoA in its work with DERA to fly conventional UAVs of a design which had become known as XRAE vehicles. This 'XRAE crate' contains all the electronics and sensors, or connections to sensors, necessary to control and fly an air vehicle with neutral or slightly negative stability, the electronics for a command and control link and electronics for a telemetry link.

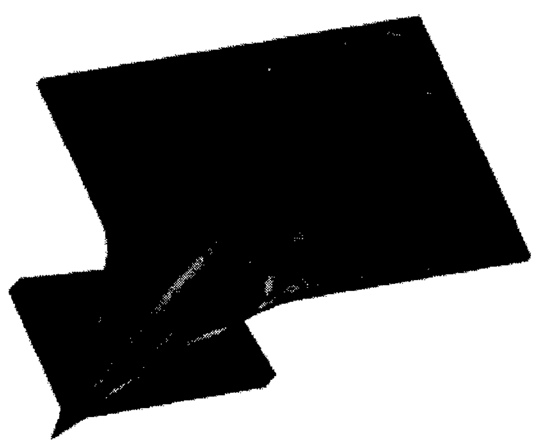

Figure 5 Initial 'Double Diamond' configuration.

7.2 Configuration Studies

The initial task of the group was to select a configuration for the vehicle. Configurations were suggested by most members of the group, ranging from the relatively conventional to the outlandish. Following parametric studies a 'Double Diamond' configuration (Fig. 5) was chosen.

However, following initial aerodynamic assessments, it was decided that the inclusion of the close-coupled canard represented too great a risk and the design evolved into a single diamond wing with dorsal engine intake, Fig. 6. Based on the students, ever optimistic, forecast of an expected first flight of the UAV in August 1999, they named it Eclipse due to the total eclipse of the sun over parts of the UK and Europe on 11 August 1999.

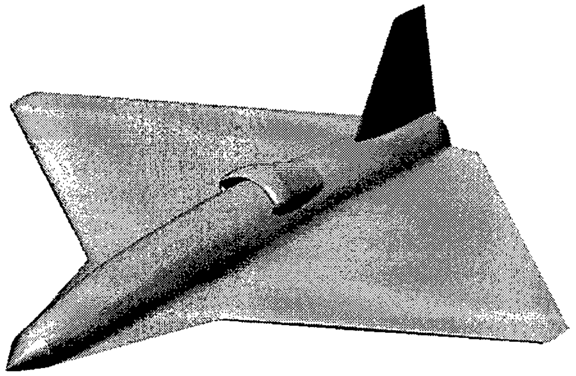

Figure 6 Final configuration of the Eclipse UAV.

7.3 Group Organisation

Although all members of the group took part in the initial configuration selection, they all selected individual roles for the project at the start. Due to the limited numbers involved, even at the start and to reduce to only 11 during this last year of the project, students generally took on more than a single role. However, in addition to the overall tasks of programme management, certification, cost etc., the group arranged itself into four major areas:

1) Aircraft systems (engine, fuel, flight controls, electrical power and physical interfaces with the XRAE crate).
2) Structural Design (including integration of all equipment).
3) Flight Controls and Simulation (concerning interpretation of aerodynamic data and development of the flight control laws to be programmed into the XRAE crate).
4) Aerodynamics (focusing on configuration issues, aerodynamic predictions, wind tunnel testing and intake design).

Roger Myers from BAe Brough Design took on the role of GDP chairman for BAe and Pete Thomasson, initially, took on this role for CoA. During 1999 Robert Jones took on the role of CoA chairman, to release Pete Thomasson to provide increased assistance to the project in his area of personal expertise, flight control law development and simulation.

7.4 Structural Design

The design of the Eclipse structure is based on construction techniques used in the production of previous vehicles of similar size for the CoA and DERA. These use hand lay-up of composites to provide foam core/composite skin, honeycomb sandwich and monolithic composite structures. Due to the restricted budget available, only a single vehicle was to be produced and so tooling costs had to be minimised. TASUMA UK Ltd, the supplier of previous similar size vehicles to CoA and DERA, was engaged to manufacture the air vehicle with the above considerations in mind.
The basic structure consists of a single piece foam core wing, skinned with carbon. A central bath tub in this wing houses the engine (with tail pipe and inlet duct) and the fuel tank. The XRAE crate is mounted on a carbon channel beam extending forward of the wing. The fuselage is effectively a fairing simply reacting local aerodynamic loads.

It will be noted that the construction used does not allow a great deal of scope for modification of the configuration. However, there are some possibilities through alteration of the forward fuselage 'fairing' and through items which might be attached to this and the 'customer' (CoA and BAe) accepted the limitation in order to reduce design risks and limit cost. It should also be pointed out that the cost of airframe manufacture itself, whilst significant, is not the major cost when compared to aerodynamic and control law development that would be necessary, were the configuration to be changed in the future.

7.5 Systems

As previously indicated, the XRAE crate was to be used to provide many of the necessary functions for the UAV. However, it requires connection to a number of external items of equipment to do this. These include power supplies, antennas, actuators and air data sensors. Whilst many of the items are apparently off-the-shelf bought-out equipment, in practice some items have proved difficult to obtain at all and the restricted budget has caused difficulties for obtaining others. Credit must be given to the student responsible for identifying suppliers of the necessary equipment for obtaining it at not only significantly reduced cost but even, in one case, on 'free loan'.

The actuators necessary for operation of flight controls and undercarriage are high quality model aircraft items. They are in fact being used in the new small, delta configuration, surveillance UAV developed by CoA for DERA, the A3 Observer but it should be emphasised that they were selected only following testing by CoA to ensure they provided the desired characteristics, as manufacturer's data does not provide the necessary information.

The single main item of equipment open to selection by the group was that of the engine. After survey of a number of potential units the AMT Olympus engine was selected. This produces a maximum thrust of 190 N at a fuel consumption of 400 gm/minute. However, again the manufacturer was unable to provide all the information on the engine necessary to producing the control algorithms for integrating it into the flight control system. Therefore, the engine was obtained and a test rig produced to allow the necessary information to be gained.

The fuel system normally used for the AMT engine was not considered feasible for the durations required in this case. Therefore, a welded aluminium tank was designed allowing operation of the engine in all positive 'g' manoeuvres. Whilst this will not allow the aircraft to perform inverted flight, the XRAE crate cannot function in this attitude either.

The undercarriage and retraction mechanisms were initially selected to be off-the-shelf model aircraft items but the potential supplier ceased operation. Therefore, a similar design, using pneumatic retraction and brakes controlled, along with the nose wheel steering, by the same type of actuators as the flight controls has been developed.

7.6 Flight Control and Simulation

Whilst the XRAE crate provided the necessary hardware to support a fight control system for the Eclipse, a new set of control algorithms was necessary to match its characteristics. A full 6 degree-of-freedom model of the air vehicle has been developed. This uses aerodynamic derivative estimation from wind tunnel test data and empirical estimation methods such as ESDU and DATCOM.

The model and simulation have been developed using Advanced Continuous Simulation Language (ACSL), which has previously been very successfully used in support of the CoA/DERA work on UAVs. Two complete models are being produced. The first has all discontinuities removed and is used to develop the basic laws and augmentation requirements. The second model includes discontinuities and quantisation errors and will form the basis of the flight simulation work to assess the vehicle's anticipated behaviour. It can also be used to explore the flight envelope during normal flight and failure cases or determine the sensitivity to errors in the data used to build the model and develop strategies to deal with these.

7.7 Aerodynamics

From the outset it was intended that Eclipse would be longitudinally neutrally stable and that, although a fin and rudder would be present for initial flights, the vehicle might be flown later without these. Therefore, accurate prediction of the air vehicle aerodynamic characteristics, both lateral and longitudinal was essential to successful development of flight control laws for the vehicle.

A major contribution to determination of aerodynamic characteristics was obtained through the opportunity to perform wind tunnel tests on the configuration. A tenth scale flat plate wing model with fuselage shaping was produced with the intention of testing in a small blower tunnel at BAe Warton. However, at the point of testing, the 4 m LSWT was free and used instead, Fig. 7. The type of model used provides a relatively cheap method of obtaining representative aerodynamic data and the small model was 'calibrated' by also testing a flat plate model of a similar configuration for which data at a Reynolds number close to that of Eclipse was available.

One key objective of the tests was to determine the optimum forward fuselage strake design necessary to maintain neutral stability at high incidence and three strake configurations were tested. Trailing edge control surface effectiveness was investigated through bending of the wing plate using cuts in the trailing edges and the effects of spoilers, to provide lateral control in the 'fin-removed' case, were investigated.

The wind tunnel tests showed that the configuration has essentially linear characteristics in all axes, up to around 10^{o} incidence. With increase in incidence the configuration becomes progressively more stable (longitudinally). The forward fuselage strakes counter this tendency and with the fin the configuration maintains positive lateral/directional stability up to around 20^{o} incidence. This is close to the maximum trimable incidence using inboard trailing edge devices alone for pitch control and give a C_{Lmax} of around 0.8.

Data from the wind tunnel tests with regard to the spoilers suggested that these alone would have difficulty providing lateral control without the fin and, since they were not required for other reasons, they were deleted from the vehicle, at least for the present.

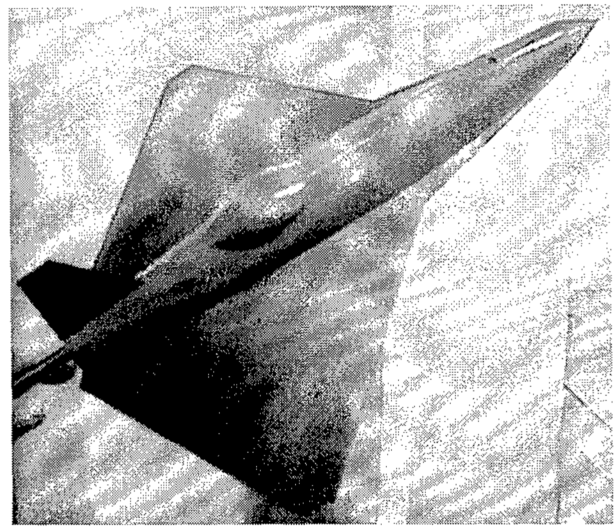

Figure 7 Eclipse model tested in the LSWT at Warton

One other area of aerodynamic risk not address by the wind tunnel tests was that of the engine intake. The choice of a dorsal intake and constraints on equipment positioning within the fuselage led to a short highly off-set 'S' duct, which, in addition, needed to accommodate a rapid expansion in area to cater for a cooling flow around the engine casing as well as one into the centre of its centrifugal compressor. CFD has been used to investigate this aspect. An Euler method was used to investigate the external flowfield in the vicinity of the intake. A Navier-Stokes method was used for examining internal flow characteristics in the duct. Whilst a 'dead' area close to the wall of the duct after the knee was identified using the latter analysis, the affected area would bypass the engine as cooling flow with the flow into the core predicted to behave well. This finding will, however, be born in mind particularly during ground testing of the engine when installed, with temperatures being monitored appropriately.

7.8 Overall Project status

At the time of writing, construction of the air vehicle is at an advanced stage, a number of the bought out items have been procured and arrangements for testing of the engine are being made. Development of the flight control system is well underway and, whilst this is recognised as one of the critical paths to first flight, additional resources from the student group and Pete Thomasson are being applied to this. Following completion of the airframe and some structural tests, it will be equipped with various equipment items at CoA and the XRAE crate, programmed with the relevant flight control laws etc. The aim at present is still to fly within the year of the eclipse of the sun, with a first flight programmed in November.

Three of the students involved in this project gained some useful additional experience earlier this year when they presented a paper on there work on Eclipse to the RPV/UAV Systems conference in Bristol, Ref 22. This paper provides further details on the work on the project up to that point in time.

8. GDP FOR THE 1998 INTAKE

There is considerable interest around the world at present in Blended Wing/Body (BWB) configurations. These have been suggested for a number of different roles, in particular, very large, 600+, passenger airliners and global range military transport aircraft. They represent an attempt to side-step the law of diminishing returns we see in trying to extract further gains in efficiency (both fuel and economic) from the conventional distinct wing, fuselage, trim surface configurations. However, they bring a number of difficulties, not least, the fact that many of our conventional design methods rely on essentially empirical data and are not easily applied to any novel configuration. In addition, the functions of the various elements and applicable analysis techniques for conventional aircraft allow us to break the design problem down in a way that the physically integrated BWB configuration does not.

In keeping with the world wide interest in BWB configurations, the CoA has put together a programme of research activities aimed at addressing some of the issues surrounding them. This involves individual research of MSc students on a number of courses and GDPs on both the Aerospace Vehicle Design (AVD) and AE courses. The estimated total commitment of staff and student time, at present defined for the full 3 year programme, is approximately 76,000 man-hours.

The GDP for the 1998 intake on AE is aimed at design, manufacture and operation of a sub-scale demonstrator of a BWB. Thus, the major initial task for the eleven students who began this project was to produce a preliminary design for the full-size BWB which would be demonstrated at full scale.

At the outset the students chose tasks for the preliminary design of the full-size vehicle covering the full range of disciplines that one would expect. In addition, they provisionally chose both technical and management tasks for the sub-scale demonstrator phase.

The CoA chairman for this GDP is Howard Smith, who is Course Director of the full-time AVD MSc and is also leading the BWB programme as a whole. He has performed a great deal of the preparatory work for this AE GDP and the AVD GDP, which worked on initial detail design of a full-size BWB and performed by students on that course during the period October 1998 to May 1999. The BAe chairman, Philip Wright of Design at Warton, is himself a former student on the AVD course.

At the time of writing, this GDP has completed the preliminary design of the full-size BWB (Fig. 8) and has now moved on to the design of the sub-scale demonstrator vehicle. Due to loss of one member of the group and some lessons learnt by the 1997 intake GDP, there has been some reallocation of the tasks relative to the provisional choices made at the beginning.

As with the 1997 intake, the XRAE crate will be used to provide the flight control etc. hardware. In addition, present intentions are to use the same propulsion unit, the AMT Olympus, with only a single unit occupying one of the nacelles of a demonstrator for a three-engined full-size vehicle. It is expected that vehicle construction techniques will be similar to those used for Eclipse and that TASUMA could well be the manufacturer. However, this vehicle is at present planned to be around twice the size and mass of the 2.2 m span and 37 Kg mass predicted for the Eclipse UAV.

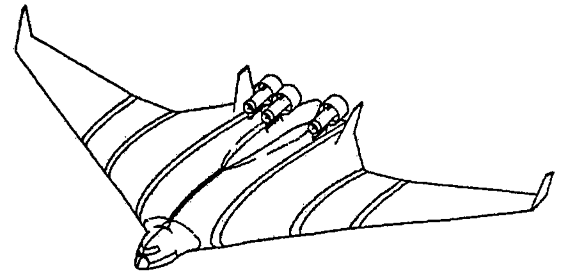

Figure 8 Full-size BWB configuration to form basis for 1998 GDP sub-scale demonstrator UAV.

9. GDP FOR THE 1999 INTAKE

The subject chosen for the GDP for the most recent intake on the AE course is again that of a UAV. However, the role is different to that of either of the previous two GDP UAVs.

The CoA has for some time had an interest in environmental monitoring of the atmosphere and in fact has operated a Jetstream aircraft to sample exhaust gas plumes for power stations etc.. In addition, the Astronautics and Space Engineering Group within the CoA has an interest in remote sensing, both the technologies involved and analysis of the data collected.

There have been a number of suggestions made that UAVs could be used as 'surrogate satellites' for remote sensing purposes, either proving payload or techniques prior to committing to a satellite launch or permanently replacing satellites in some roles. In fact, the CoA has already performed a small study funded by the European Community using very simple UAV systems at low altitude to prove some of the techniques.

For a number of the in-situ and remote sensing roles, for both environmental and other purposes, it is important that the vehicle stays on-station and often at reasonably high altitudes for long periods. This provides a challenge for all the disciplines of aeronautical engineering that has interested staff and students at the CoA for some time, Ref 23. Therefore, the GDP for the 1999 intake of the AE course has picked-up on these interests in attempting to design, build and fly a 'high' altitude 'long' endurance small UAV.

The 12 students in this group have been set the task of flying a proof-of-concept vehicle at 12 km altitude. Again, to reduce time and cost the XRAE crate will provide a basis for the vehicle systems. However, in this case the fact that this crate has been developed in stages, rather than as an integrated whole, and along with the various support equipment, batteries etc. weighs around 10 kg, becomes a real problem. Given time and money, a package performing the same functions as the present crate could easily be developed at half its present weight and probably much less.

Recognising the weight reduction in the crate which could be possible, the students have been asked to design an 'ideal' vehicle and a 'real' proof-of-concept vehicle. The former would have a re-engineered crate and be capable of carrying a 5 kg payload for 24 hours at 12 km with a 14 km ceiling, whilst the latter will use the present crate to carry a 1 kg

payload at 12 km for long enough to prove the fuel consumption figures etc.

At present the students are arranged in three competing teams, working on configuration designs to be presented to the 'customer' at their next lecture module in November 1999. Beyond that point they will move on to the design of the proof-of-concept vehicle, as a whole group. There are indications of possible interest from the Astronautics and Space Engineering group and companies they are involved with in production of a real demonstration payload for the vehicle to fly. This could, if all goes well, lead to the 'ideal' vehicle becoming a possibility.

The chairmen for this GDP are Robert Jones for CoA and Garry Shadbolt, one of the graduates from the 1995 intake of the AE course, for BAe.

10. DISCUSSION

10.1 The GDP as a Teaching Method

The general principle of a GDP as a teaching method, that the best way to learn the design process is to do it for real, has been well proven over the years on the full-time AVD course. However, that course only attempts to cover part of the design process and is particularly aimed at designers. The objective of the GDP on the AE course is more ambitious in that it attempts to bring in all the technical (and some non-technical) disciplines necessary to progress an aircraft project from specification to flight. As a result, the AE GDP has successfully allowed students from various backgrounds to play a full and useful part in the project.

In addition to providing first hand experience of technical aspects which must be considered in a real project, the GDP gives very real experience of the difficulties of managing and controlling a project with constrained manpower, budget and time and needing to prove safety. Experience with the GDPs on the AE course to-date have proved them to be all too 'real' with over-runs in terms of cost and time. At least these have been of manageable proportions and no-one's career or reputation has been destroyed be the problems (at least not yet!).

It has not only been the students that have learnt valuable lessons during the course of the GDPs. Staff at CoA and senior engineers at BAe have also learnt much about each other's capabilities. The advantages and disadvantages of each other's normal methods of working and how these might be applied to advantage on future projects outside the AE course have been highlighted.

There is no disguising the fact that the AE course as a whole is very demanding and, as a result, students have withdrawn from the course. It requires a student to study over three years a course equivalent to a full-time one year course, hold down their job and fulfil their family commitments, often at a point in their lives and careers when their circumstances are changing rapidly. The demands of the GDP adds to this. However, unlike the lecture modules and individual research elements of the course, it also brings with it a drive from being a member of a group, working towards a common end. In fact, it is clear from the intakes on the course to-date that, when a students time is limited, it is the other elements of the course rather than the GDP that suffer and particular emphasis has continually to be placed on the individual research, particularly, to ensure this does not get left out.

One of the major non-technical benefits of the AE course and, in particular the GDP, to both the sponsor and students individually is the personal contacts that are made during the course. These provide links between BAe Military Aircraft & Aerostructures' (MA&A) sites and departments. Students have been drawn from BAe's sites at Brough, Dunsfold, Farnborough, Salmesbury and Warton. There disciplines have included:

- Aerodynamics
- Airworthiness
- Avionic Systems
- Design
- Flight Test
- Materials
- Manufacturing Dev. and Test
- Reliability
- Structural Test
- Structures
- Systems Engineering
- Wind Tunnels

The personal contacts formed between the students during the course and GDP, along with those made outside the groups to progress work on the GDP, are of lasting benefit to organisation. Whilst it may not actually be another student at another site or in another department that needs to be contacted in the future, they provide a useful and known starting point who is likely to be helpful in locating the person who is actually required.

As the second group of students on the course has only just graduated, it is a little early to judge the direct benefits to BAe and the students of the course and GDP. Certainly the course can not be seen as providing a guarantee of accelerated progression through the company for its graduates but indications are that some who have completed the course have already made good use of their experience.

10.2 Developments for the Future

As indicated above, the AE student intake covers a wide range of experience and discipline backgrounds within BAe. However, Cranfield University's regulations prevent a course being provided exclusively for a single employer. Therefore, it was always intended that its intake would be widened to encompass students from other employers from the aerospace sector. Therefore, although BAe MA&A remains the predominant customer for the AE course, there are students on the course from other parts of BAe , DERA and MoD.

In future. it is hoped to widen further the sponsors of students on the course. It should be emphasised that a particular attraction to BAe MA&A was that they could integrate lectures by some of their own staff with the material provided by Cranfield. Therefore, the effects of a wider audience on the allowed material for such lectures may need to be considered. However, the difficulties this might create are outweighed by the advantages gained by all sponsors of students in having their employees exposed to the knowledge and experience of students from other sponsors with a different perspective. In fact, it has long been recognised by the regular sponsors of students on the full-time AVD course, from around the world, that one of the major benefits of the course is the opportunity for the students to mix with those from other countries and parts of the aerospace industry.

To-date subjects of the GDPs have been limited to modifications of CoA's own A1 aircraft and UAVs. These have apparently provided topics which meet the basic objectives of this element of the course. Whilst further modifications to the A1 could be considered and further UAVs, or modifications of the present ones, are also possible, it would be good to find new subjects for GDPs, to ensure student interest.

The CoA does operate other aircraft which could be modified and often works on one-off modifications of BAe's own aircraft. Therefore, these could provide some possibilities. A more ambitious subject would be a manned aircraft designed from scratch but this would not sensibly be possible within a single GDP, so would need to be broken down into sections. At the other end of the scale would be a 'virtual project' which would not actually produce flight hardware but possibly wind tunnel models etc. This would certainly limit costs involved in the GDP but whether it would capture student interest and provide the same concentration of mind on safety issues is not clear.

11. CONCLUSIONS

Although the GDPs, and AE course as a whole, is and will continue to be very demanding of both students and staff involved, it provides an effective approach to tackling the problems of an engineer gaining real practical experience in today's employment environment. It also offers additional opportunities for all parties concerned to benefit.

Within the relatively short time period for which it has been running, the GDP element of the AE course has proved to be a very effect tool in teaching the students about the many technical and non-technical facets of typical aerospace projects. It has allowed students from many disciplines within BAe MA&A and beyond to be exposed to the real practical problems and difficulties in applying their own and other's aerospace engineering knowledge, in a relatively limited risk environment.

Personal links between students from different sites and departments and between CoA staff and a range of individuals in BAe have been formed, to the future advantage of all concerned. In addition, useful lessons about the general working practices within BAe and CoA and where/how these can be applied to best advantage in future have been learnt.

In the future, it is hoped to widen further the course intake to encompass more organisations within the aerospace sector. New subjects for GDPs will also need to be identified. However, the basic requirements of a project covering a wide extent of the design process, within real constraints, will need to be retained.

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